

# Ubiquitous Computing

## For Dynamic Condition Based Maintenance

Aitor Arnaiz Irigaray and Eduardo Gilabert  
*Dept. of Manufacturing Processes - Fundación Tekniker, Spain*  
Erkki Jantunen  
*VTT Technical Research Centre of Finland*  
Adam Adgar  
*University of Teeside, UK*

### Abstract

**Purpose** - The purpose of the paper is to describe a flexible architecture concept to provide an ubiquitous computing framework where condition based maintenance data and information can be easily accessed, and maintenance decisions may be performed wherever required.

**Design/methodology/approach** - The architecture is based on a platform of intelligent web services, and logically structured decision layers based on the OSA-CBM definition, from condition monitoring to decision support, and provides automated extraction of results. The application of web services is demonstrated, first related with an original vision on the adoption of mobile devices for dynamic maintenance management solutions, and then with a more conventional web based predictive maintenance management system.

**Findings** – Scenarios for the upgrade of existing preventive maintenance practices towards condition based strategies are sufficiently different to require customised solutions. A web based platform can work with such differences in a cost-effective way.

**Research limitations/implications** - Further research can expand the actual platform by embedding new complementary web services.

**Practical implications** – Condition based strategies can provide clear savings in many maintenance activities. The platform described will provide the necessary flexibility to industrial users to manage the volume of data and information needed in condition based maintenance (CBM).

**Originality/value** - The platform is flexible enough to provide intelligent processing ‘on-demand’ and ubiquitously, with a three-level configuration of web services, agents and interfaces that facilitates interoperability with existing legacy systems. Finally, the platform can grow according to the needs of the user (e.g. new information, increased knowledge on the process, new measurements, etc)

**Keywords** Condition monitoring, mobile devices, web services, OSA-CBM, e-Maintenance

**Paper type** - Research paper

## Introduction

At the present time, maintenance is going through major changes. The industry and also the public are realising that the efficient use of industrial assets is a key issue in supporting our current standard of living. In this context, efficiency means producing good quality products without interrupting production schedules due to unnecessary breakdowns.

With the current, ever-growing demand for improvements on system productivity, availability, safety, product quality, customer satisfaction and taking into account the trend for decreasing profit margins, the importance of implementing efficient maintenance strategies becomes unquestionable. In this setting the maintenance function plays a critical role in a company's ability to compete on the basis of cost, quality and delivery performance. Therefore, maintenance is increasingly taken into account in production requirements (Al-Najjar & Alsyoud 2003; Crespo & Gupta 2006). What is more, at the very end of this changing focus on maintenance there exists a new role for the maintenance function, particularly for the manufacturing industry. Taking into account the life-cycle management oriented approach, where limits on resources and energy consumption require a sharp change in the objectives of manufacturing. This change will cause a shift in emphasis from the need to produce more efficiently to ensure customer satisfaction and profitability. Maintenance activities will hence become of equal importance to actual production activities (Takata *et al.* 2004).

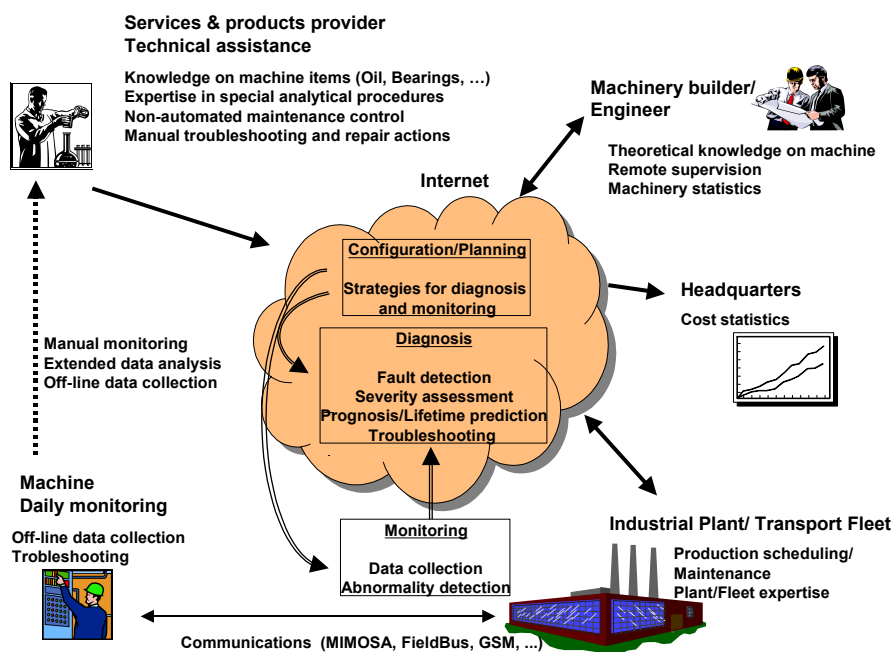
To support this role, the maintenance concept must undergo several major developments involving proactive considerations, which require changes in transforming traditional "fail and fix" maintenance practices to "predict and prevent" e-Maintenance strategies. Baldwin (2001) defined e-Maintenance as "The network that integrates and synchronises the various maintenance and reliability applications to gather and deliver asset information where it is needed. E-Maintenance can be thought of as a subset of e-Manufacturing and e-Business". Iung (2003) shows that e-Maintenance is integrating the principles already implemented by tele-maintenance, which are added to web-services and collaboration principles. Collaboration allows not only the sharing and exchange of information but also of knowledge and (e)-intelligence (new services, new processing). Such an approach takes into account the potential impact on service to customer, product quality and cost reduction (Lee 2004). The key advantage is that maintenance is performed only when a certain level of equipment deterioration occurs rather than after a specified period of time or usage. In other words, there is a shift away from current mean-time-between failure (MTBF) practices to mean-time-between-degradation (MTBD) technologies. E-Maintenance provides the opportunity for the 3<sup>rd</sup> generation maintenance and is a sub-concept of e-Manufacturing and e-Business for supporting next generation manufacturing practices (NGMS).

### *Predictive maintenance*

However, this change in maintenance concept is jeopardised by the lack of flexible and cost-efficient maintenance systems. This challenge is particularly linked to the small relevance that advanced maintenance strategies, such as condition based maintenance (CBM) and predictive maintenance (PdM), have reached so far. According to Komonen (2005) about 30% of all the maintenance activities in industrial and transportation systems in Europe are unplanned, whereas a 55% of the activities are related to planned and scheduled maintenance. That is, 85% of the maintenance strategies implies unnecessary action costs and machinery breakdowns or service actions like disassembly that have negative effects on the performance and lifetime of components. This leaves a maximum of 15% of the activities being focused on CBM strategies that presumably

accounts for the newer and more critical machinery, where cost-benefit ratio clearly favours condition based approaches.

One important reason for this lack of application may lie in the need for information. Comparing to other strategies, predictive maintenance needs much more information, in order to provide an adequate response to different tasks: Identification of abnormalities (deviations from normal operation); Abnormalities analysis for (starting stage of) fault modes recognition; Type and location of the fault; Assessment of fault severity (incipient, advanced...); Prediction on residual lifetime. Planning all of the tasks depicted above are 'knowledge-intensive', as there is an evident need of expertise to be able to handle them. Also, the knowledge gathered from previous tasks requires the inclusion of information from many different sources, which not very long ago were analysed in isolation from each other, and still today there are many actors, apart from vendors and users, that take part in this maintenance process.



**Figure 1.** Information flow among different maintenance-related actors in a complete intelligent system using condition monitoring information.

To include (and to maintain) such a knowledge-based system, able to support operators to determine best solutions is not an easy task. Knowledge in the area is still scattered, with much information existing for well known techniques (e.g. vibrations, electrical motors), but more scarce in other less well established techniques (e.g. acoustic emission, machine-tools). What is more, information is required to be adapted as new operating conditions must be controlled, as knowledge in many fields grows yearly, and finally as new devices (e.g. sensors) appear providing new information. (Arnaiz *et al.* 2004)

Based on the explanation given above, the success of this 3<sup>rd</sup> generation maintenance in a wide range of companies with non-critical machinery is based on the inclusion and application of the right support technologies. This ensures lower set up costs related to the acquisition and transmission of the information, as well as to facilitate the integration of such technologies with existing material and personal resources in an intelligent and adaptive manner.

As a consequence, one of the main aims of the ongoing EU-funded Integrated Project DYNAMITE (Dynamic Decisions in Maintenance) is to bring together a group of technologies that can be integrated in a structured way, yet flexible enough to allow the selection of a particular subset of the technologies. In this paper, the current developments are explained, with a special focus on the web services platform that allows interaction between technologies in the framework of a distributed information scenario, where technologies of interest may vary from one company to another.

### **DYNAMITE: Dynamic Decisions in Maintenance**

As indicated in the introduction, more research efforts are required to face the challenges of modern e-Maintenance strategies. One focused research direction is offered by the Integrated Project DYNAMITE, coordinated by VTT Technical Research Centre of Finland. It includes six research institutes in the UK, France, Spain, Sweden and Finland, the car manufacturer FIAT, the truck manufacturer Volvo, the machine tool manufacturer Goratu, the automation and maintenance services provider Zenon, and seven SME's representing related business areas.

The DYNAMITE vision aims at promoting a major change in the focus of condition based maintenance, essentially taking full advantage of recent advanced of information technologies related to hardware, software and semantic information modelling. Special attention is also given to the identification of cost-effectiveness related to the upgraded CBM strategies, as well as to the inclusion of innovative technologies within CBM processes. It is expected that the combination of the use of new technologies together with a clear indication of cost-benefit trade-off will facilitate the upgrade into CBM. This expectation is thought to be particularly relevant in many cases where non-critical machinery exists, and especially for the vast majority of SME companies where the distance between planned and condition based maintenance is too wide.

However, it is difficult to find a single solution that fits for all concerning the maintenance needs. Table 1, which was compiled from end user analysis during the first stages of DYNAMITE, clearly shows that it is not possible to find such a system, as existing strategies, machinery and legacy systems differ, as well as perceived technical problems and economical motivations.

**Table 1.** Summary of end-user scenarios in DYNAMITE project (Arnaiz et al. 2007)

<b>Providers</b>	<b>Plant operators</b>	<b>OEM manufacturers</b>	<b>Consulting</b>	<b>Transport (OEM + consulting.)</b>
Context	Single location (Manufacturing plant). Multiple machines	Technical Assistance Services. Guarantees Multiple locations	Specialised services (e.g. lube analysis) for multiple locations	Specific machinery on movement
Application (Components)	Milling, drilling and high speed machine tools (Hydraulic systems, gearbox, spindle)			Motors (Marine, Automotive)
Current strategy	New PM ( 10- 20 % CBM)	BDM	PM	-

Current economic motivations	Overall economic impact to the company for different maintenance strategies not always known	Uneven workload Enforce/surveil remote maintenance procedures on guaranteed machinery	Decrease downtime, repair and maintenance costs	Plan new cost –effective e-Maintenance for new equipment
Current technical problem(s)	Evaluation of machine condition depending on expert knowledge (subjective)	Improve diagnosis Communication sensors to OEM (bypass CNC)	Lack of experienced diagnosis and decisions over existing parameters	Lack of proper knowledge
Interesting technologies	Include advanced sensors Wireless communication Smart PDAs Include cost-effectiveness	Upgrade to CBM Use remote monitoring e-Maintenance. Wireless gateways Cost effectiveness	Use e-Maintenance to remotely assess expert and communicate to operators. Training systems.	Initiate predictive maintenance
Likely CBM/PM parameters (sensors)	Temperature, Voltage, Current, Oil level, Oil quality, vibration, pressure, Wear debris			

### **A three-tier structure for operation integration**

Therefore, a new concept (DYNAWeb) has been developed. This concept is best described as the information and communication platform that provides operational interaction between ‘plug-in’ technologies in the framework of a distributed information scenario, where technologies of interest may vary from a maintenance use case to another (Jantunen *et al.* 2008).

In order to develop this platform, a study of likely actors associated to future DYNAWeb activities was made. The synthesis appears in Table 2, which identifies: the main role identified in each case; the data expected; and their expected involvement in OSA-CBM layered information processing steps.

Even though some other actors may also participate in maintenance activities, such as MES or ERP systems, DYNAMITE technologies are focused on the activities related to above defined actors.

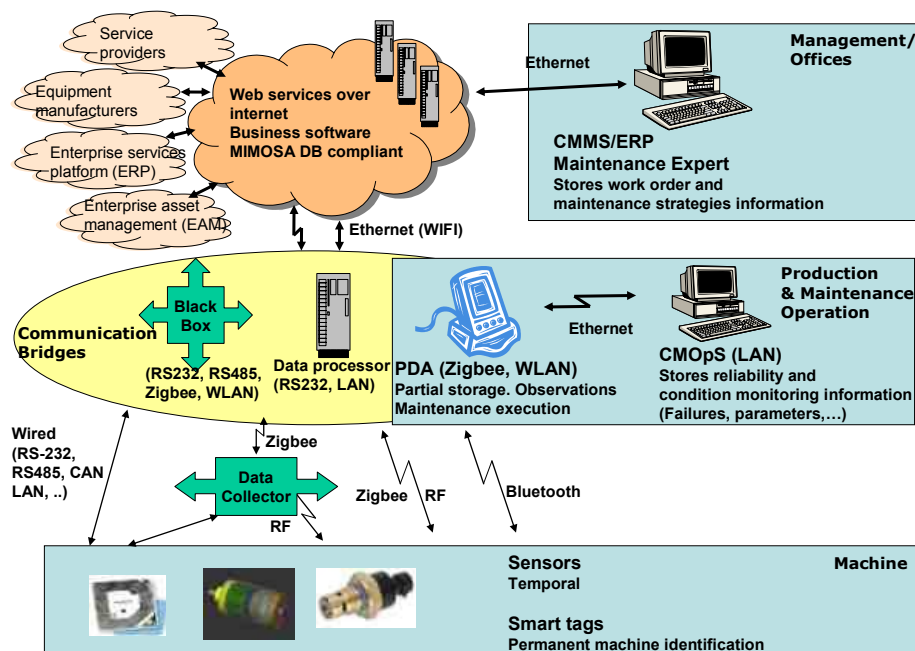
Once actors were identified, these have been framed into a flexible architecture concerning communication channels between the actors. The graphical layout indicates typical communication architecture with respect to a company where information and actors are distributed.

**Table 2.** Main characteristics of DYNAMITE actors

<b>Actor</b>	<b>Role</b>	<b>Expected Data</b>	<b>Associated OSA-CBM levels</b>
<b>Maintenance Expert</b>	Strategic decisions on maintenance in accordance with Enterprise policy	Policies	
<b>CMMS/ERP</b>	Manage life cycle of the maintenance work-orders in accordance with selected maintenance strategy	Data on spares, work orders, events, indicators	Operational Decision support
<b>Computer Maintenance Operational System (CMOpS)</b>	Support maintenance dynamic processes for selecting the best maintenance work-order and supporting it	Historical/Trend data Reliability data	Prognosis Diagnosis
<b>PDA</b>	To assist the maintenance operator in carrying out everyday tasks. To embed CMOpS functions	Operator data	Condition monitoring Signal processing
<b>Sensors</b>	To deliver data and information on machine status	Status data	Condition monitoring - Signal processing – Data acquisition
<b>Smart Tags</b>	To automate machine/part identification and deliver historical information on machine state	Identification data	Signal processing

Figure 2 provides a schematic overview of the complete system concept depicted for information and communication technologies that are considered within DYNAMITE project. This view identifies the existence of three layers (squared blue on the right of the figure) with the location of actors with respect to the company, and also stating the interoperability of these actors with different technologies.

The first level corresponds to the machine and identifies sensors and smart tags as associated to this level of interoperation. It is also expected that sensors hold temporal information concerning current condition values, with little or no historical information attached. The second level corresponds to the production shop floor and identifies two main actors: The personal digital assistant (PDA) and the Computer and Maintenance Operational support (CMOpS). It is argued that these can both hold temporal information concerning operator activities and input values, and that CMOpS will hold historical records on selected condition information. The third level corresponds to headquarters and management staff, where both tactical and strategic decisions are made. CMMS as well as maintenance expert agents are located at this level, together with information concerning scheduled operations and maintenance strategies.



**Figure 2.** DYNAWeb ICT structure

In all three levels, there is a special effort within DYNAMITE to provide technologies able to provide a flexible information and communication infrastructure, primarily based on the use of wireless systems. Thus, at the first level it is expected that most of the new sensors (some developed within DYNAMITE) will be able to communicate directly to the upper level (for instance, one of the novel options is an USB connection to a PDA i.e. the PDA acting as a flexible, powerful and portable data logger). However, for those with wired connections, a data collection system is developed so that it is possible to 'plug' conventional communications (e.g. RS232) to be converted into a Zigbee output. The second level offers three different ways of interoperation. Having in mind the central processing device of the PDA, two other systems for data storage and communication are envisaged. First, conventional existing data processing systems (i.e. SCADA) may play a role in intermediate data storage and communications. However, for those scenarios where wireless communication is a more suitable solution, a Gateway 'black-box' has been developed. Here the gateway provides a cost-effective means of channelling data from sensors in a local area to the higher level data processing systems. In all three cases it is expected that Internet communication is used in order to enable the upper layer of information processing. In this layer, business processes such as health assessment, prognosis and decision support are framed in the form of web services that can be called from any of the existing actors at lower layers. These processes are structured according to several standards in order to enhance interoperability, and are described further along this paper.

### Intelligent web services

Web services are a well known technology which has been utilised in industrial environments. They offer interoperability between independent software applications over Internet by means of SOAP protocol which enables the communication.

In DYNAWeb, in order to provide the most convenient analysis flow, information processing is understood as a distributed and collaborative system, where there are

different levels of entities that can undertake intelligence tasks. Given this, with the help of Use Case Diagrams (UCDs) using the standard Unified Modelling Language (UML<sup>1</sup>), a system architecture has been defined to identify the interactions between actors and the required functions. Of particular importance is the UCD definition for Operation, Evaluation and execution of Tasks (see Figure 3). The specification of this UCD includes 4 layers that correspond to the central information processing layers of OSA-CBM standard (Bengtsson 2003):

- *Condition monitoring*: Condition monitoring receives data from the sensor modules and the signal processing modules. Its primary focus is to compare data with expected values. The condition monitoring layer should also be able to generate alerts based on preset operational limits or changes in the trend.
- *Health assessment*: It receives data from different condition monitoring sources or from health assessment modules. The primary focus of the health assessment module is to prescribe if the health of the monitored component, sub-system or system has degraded. The health assessment layer generates diagnosis records and proposes fault possibilities. The diagnosis is based upon trends in the health history, operational status and loading and maintenance history.
- *Prognostics*: This module takes into account data from all the prior layers. The primary focus of the prognostic module is to calculate the future health of an asset, with account taken to the future usage profiles. The module reports the failure health status of a specified time or the Remaining Useful Life (RUL).
- *Decision support*: Is in this context related to “Schedule work orders”. CMMS (Computerized Maintenance Management System) schedules work orders based on component predictions. After that it distributes work orders to different operators (PDAs). The PDAs need to read the smart tags in order to learn about the components (Adgar et al, 2007).

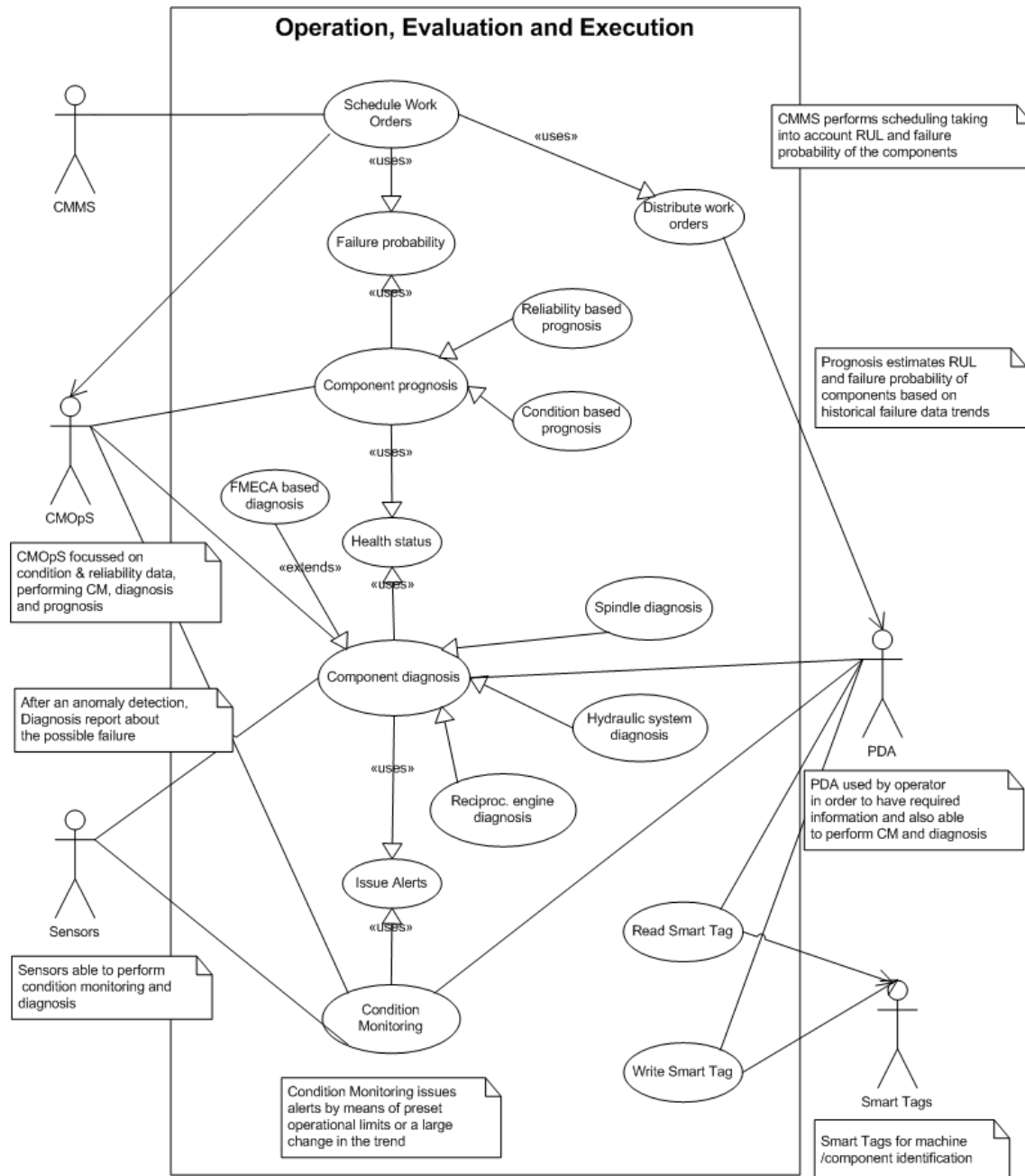
One of the challenges is to match the semantic web concept to the maintenance function. In this way, information transmitted and received via the Internet must be specified in ontologies. The ontology represents the knowledge in Internet (Fensel 2001), defining in a formal way the concepts of the different domains and relationships, with ability to perform reasoning over this knowledge. In this case the definition of ontologies has been performed starting from the standard CRIS (Common Relational Information Schema) defined by MIMOSA<sup>2</sup> (Machinery Information Management Open System Alliance). CRIS represents a static view of the data produced by a CBM system, where every OSA-CBM layer has been associated to ontology (Lebold *et al.* 2007).

---

<sup>1</sup> <http://www.uml.org>

<sup>2</sup> <http://www.mimosa.org>





**Figure 3.** Use case diagram for Operation, Evaluation and Execution.

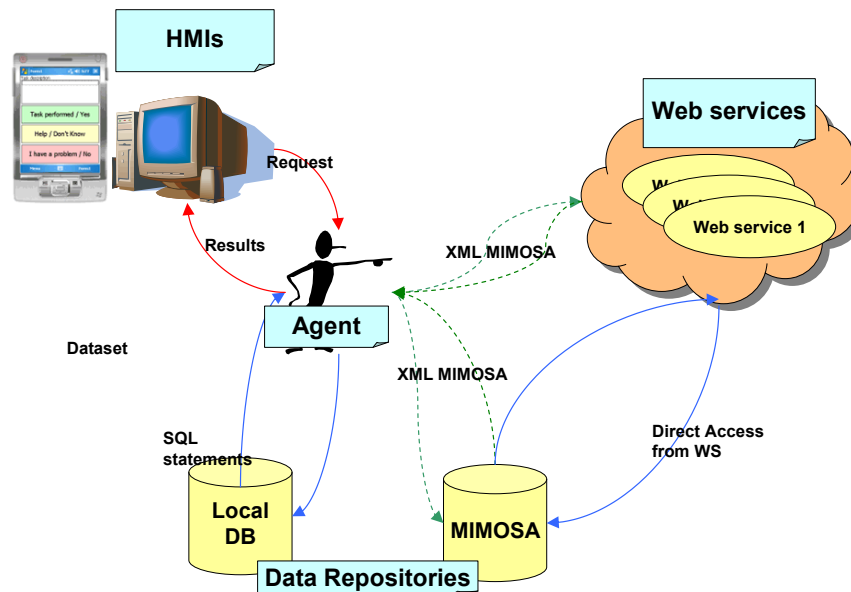
OSA-CBM was developed around MIMOSA CRIS that provides coverage of the information (data) that will be managed within a condition based maintenance system. It defines a relational database schema with about 400 tables for machinery maintenance information. In short, CRIS is the core of MIMOSA which aims to the development and publication of open conventions for information exchange between plant and machinery maintenance information systems, and DYNAMITE web services are built using CRIS standard for interoperability and internal information processing.

Another great challenge is to approach this concept for everyday computing resources (e.g. SMEs), as well as for the forthcoming mobile services. In this sense, with regard to the usage of these web services, there are three main elements defined which take part in the communication:

- Human Machine Interfaces (HMI) actor, that is, a software interface for the operator sitting at the desk or walking with the PDA and interacting with local or central database systems asking web services to process specific information.
- Agent for communicating with DYNASWeb web services. The agent is able to get the needed data from other sources, translating it into the ontology language. In this way the agent acts as an interface between HMI and web service.
- Web service, performing the requested service, supported by ontologies.

With this configuration in mind, flexible data interaction architecture has been developed to provide the best access depending on agents and data repositories available. This means, that, once the operator has requested a specific result, the agent can use mainly two different communication options, as shown in Figure 4.

- Direct communication with Database (DB) can be performed if the Database fulfils the MIMOSA specification. Then the agent only transmits XML<sup>3</sup> commands to the web service, which in turn accesses the DB for data.
- If local database is not MIMOSA compliant, the agent may choose to send the data in XML format.



**Figure 4.** Communication options between HMI, agent and web services, depending on existing database characteristics

As an example of this interaction, Figure 5 depicts a sequence diagram to request a diagnosis service, with direct communication sending data in XML format.

<sup>3</sup> XML (Extensible Markup Language) is a standard for the interchange of structured information between different platforms.

The performance of every diagnosis function follows next steps:

- Acceptance and validation of XML file.
- Extraction of data from XML file
- Generate diagnosis alerts with associated probabilities and severities. Depending on component, the service can manage one or more object to issue a health assessment:
  - A Bayesian Network
  - A CLIPS expert system: based on rules
  - FMECA definition
- Parse alerts to XML file
- Return XML file to agent
- It is necessary to perform a visual inspection or other test, the agent could request in a second step the diagnosis service with added information.

In this example, it is interesting to point out how both mobile PDA and CMOpS actors share the same access to the web services. Lastly, this example shows that it is possible to frame existing process systems within CRIS formatted web services, to take advantage of already existing intelligence. For instance, one of the existing diagnosis processes is based on previously developed systems (Gilabert & Arnaiz 2006) using Bayesian Networks to facilitate a model that can work with uncertainty and can also be adapted with feedback information. In this sense, most web services have been developed using .NET<sup>4</sup> platform as a web application, using Microsoft Visual Studio .NET programming environment, and the database implemented with Microsoft SQL server 2005.

### **Web services results and application**

The web services system depicted has been fully developed and is now being tested on different real use cases that were specifically derived from scenarios identified in Table 1. In particular, there are now three main test scenarios (an OEM manufacturer and two manufacturing and assembly plants that are testing the 25 different modules that have been developed under DYNAMITE Project and connected to the web platform. Also quite a number of web services are available to the project consortium that can be mainly accessed from two different operator sources: From a typical web site that implements a maintenance management prototype<sup>5</sup> and from direct access with PDA. These options are shown in detail below.

#### *Application of mobile devices*

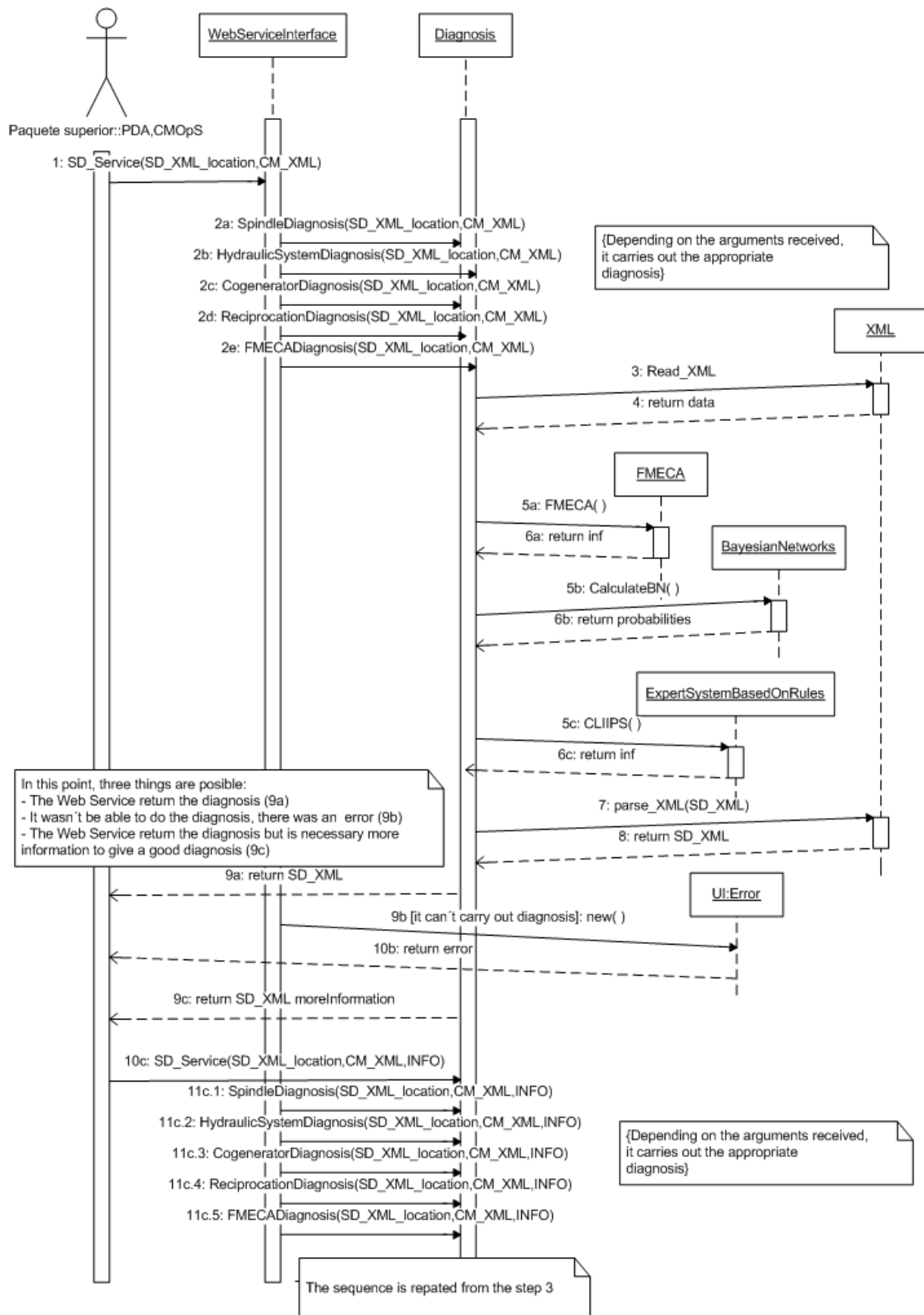
The role of a PDA device is critical in e-Maintenance systems because the PDA acts as a mobile user interface to the whole system. Through the PDA the maintenance engineer gets information from the Computerised Maintenance Management System (CMMS) such as work orders and availability of other personnel or spare parts etc. The PDA can guide the maintenance engineer to the machine both at plant level and at more global level (map/GPS system) if necessary and help to identify the machine by communicating with smart tags in machines. At the machine the PDA can provide information of the maintenance history of the machine through communicating with the

---

<sup>4</sup> .NET is a Microsoft project for making a new software development platform with special focus on hardware independency and fast development of applications

<sup>5</sup> Available at <http://tessnet.tekniker.es>

CMMS using Wireless Local Area Network (WLAN). In addition to maintenance history the results of condition monitoring and diagnosis can be passed to the PDA.



**Figure 5.** Sequence diagram for diagnosis web service

Usually the PDA is a thin client i.e. most of the data is located and processing takes place in the central computers providing e-Maintenance services. Since it is not always easy to automatically diagnose what is the condition of a machine, it is possible to include the condition monitoring and signal analysis capability also to the PDA. The PDA can also communicate with the local intelligent sensors or be equipped with an AD-card through the Universal Serial Bus (USB) which enables the use of any kind of sensor in practise. In case of additional measurements the normal way for the PDA to work is to communicate through the WLAN and rely on Web Services for signal analysis and diagnosis. Unfortunately, even today, good connection to the Internet cannot be guaranteed in all environments and also the connection might still be slow. Therefore, the PDA can store a local copy of the vital parts of the database and consequently tasks related to the definition of machinery and all kinds of findings related to them can be recorded off-line and uploaded to the Server at a suitable moment. Finally, certain intelligent web services can be downloaded to the PDA so that certain tasks (e.g. cond. monitoring or partial diagnosis) can be done locally, using the same XML protocols used over the web. In this sense, the web services framework provides a third way to work with in case the Internet communications are not yet good enough.

In addition to the above the PDA has the normal features often needed in every day work e.g. calendar, word processing etc. One very important feature in the use of the PDA is the help it can give in carrying out the actual maintenance tasks and after they have been performed, it provides the means of reporting the work in the form the CMMS can use. Again the handling of work orders and reporting related to them can be done off-line.

An operational example of the use of the above-described technologies may be described:

- 1) CMMS re-schedules work orders based on web services analysis on component predictions.
- 2) Re-scheduled orders are retrieved by the PDA when maintenance personnel become available.
- 3) Maintenance orders are issued depending on proximity of a given PDA to the faulty machines.
- 4) Additional information retrieved, as required, from wireless sensors and smart tags.
- 5) Machine health measurements recorded before and after the maintenance action to confirm solution of the problem addressed.
- 6) Details of actions taken and result achieved are stored locally on smart tags.
- 7) Automatic reports generated to complete asset management records.

The specifications of the handheld PDA device, including hardware and software requirements have also been defined. The primary hardware elements include the PDA itself, the wireless hardware and the RFID or smart tag hardware. Among the choices the following might be outlined: 1) The operating system should be a Windows Mobile which supports the use of all software modules developed in Dynamite project. 2) VGA screen resolution is used so that the use of DYNAWeb modules becomes possible in practise e.g. CMMS. 3) The PDA platform supports various types of wireless communication technologies. A database of potential PDA hardware platforms has been

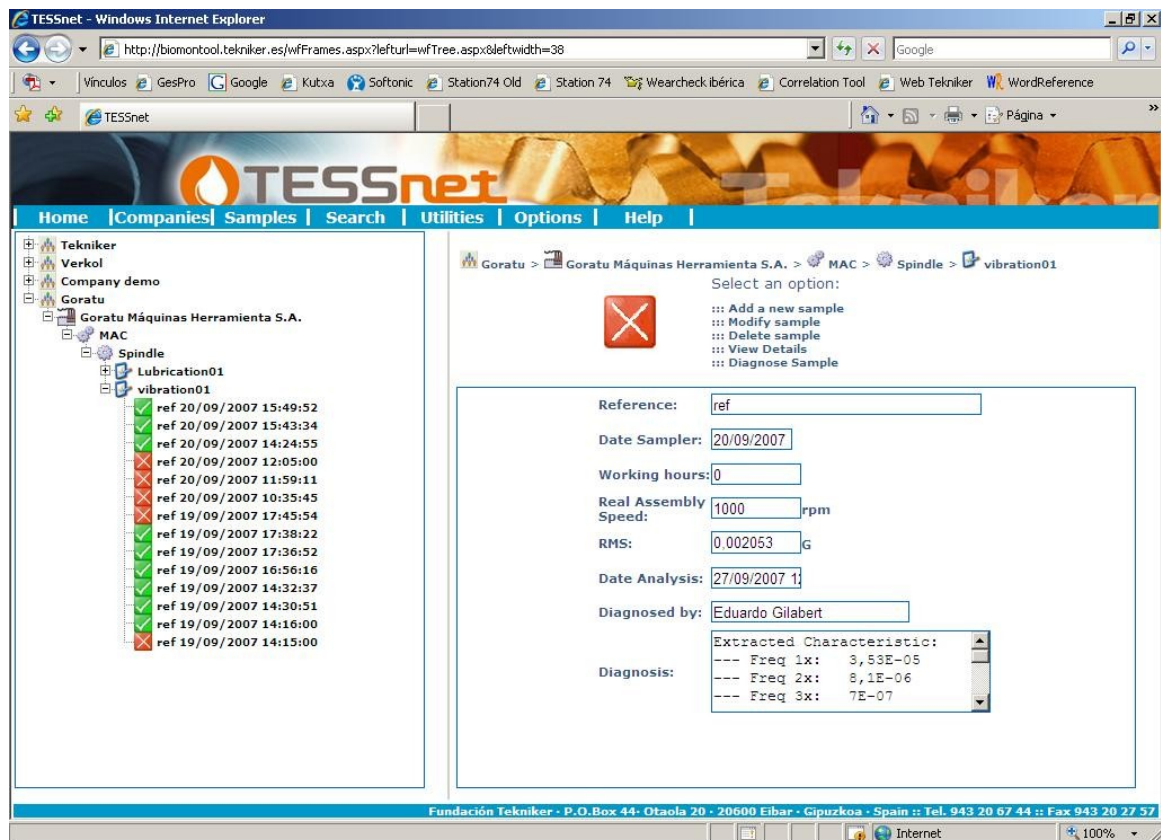
built. Due to the rapid development of hardware and differences in markets in various countries no specific device or manufacturer is recommended.

#### *Application at web site*

In a more traditional approach, it is also likely that part of the maintenance tasks are performed from a local support work station. In order to show this feasibility, TESSNet is an example tool used in this framework to perform different tasks by means of DYNAWeb web services. It is a predictive maintenance management system based on oil, vibration and temperature analysis which performs an automated condition monitoring, diagnosis, prognosis and decision support. This tool is web-based, collaborative and also offers a distributed management system, with user control access and different access rights. The platform stores measurements both from on-line and off-line sensors as well as laboratory analysis results, using a hierarchy of components: Company, Plant, Machine, Assembly, Sensor and Measurement. These can be observed at left hand side in Figure 7.



**Figure 6.** Examples of the available functionality with the PDA.



**Figure 7.** Web services diagnosis and condition monitoring results transferred to TESSNet web interface

The system is connected to the intelligent web services in order to perform the advanced functionality according to OSA-CBM layers. In this way, the feasibility of this approach is demonstrated, where the functionality is not embedded in the platform, but is distributed within a framework.

## Conclusions

This paper presents an integrated maintenance platform DYNABWeb, that refers to the ICT architecture concerning intelligent web services and communications that provide support to the new maintenance concept developed in DYNAMITE project. This concept is focused on the increase of usage of condition monitoring technologies, with the aim of providing cost effective Predictive Maintenance solutions by extending the use of a selected set of new technologies within the area of maintenance activities.

This development is performed within a flexible architecture concept to provide flexible data and information management, where core concepts such as e-Maintenance and OSA-CBM architecture are followed. Web services provide generic functionalities supported by ontologies. At client side, the agents act as links among actors and the semantic web services.

A complete system has been already developed with two different maintenance actors that request web services process support. First the use of mobile devices is described. They can access on or off-line to the provided services. Second, a web based predictive maintenance management system is presented.

The ultimate objective of this development is to facilitate the access of every company to the great changes and opportunities that are occurring in maintenance today. It is

expected that the potential of this new e-Maintenance approach really gives opportunities to gain remarkable economical benefits to all range of companies.

### Acknowledgements

The authors gratefully acknowledge the support of the European Commission Sixth Framework programme for Research and Technological Development. This paper summarises work performed as part of FP6 Integrated Project IP017498 DYNAMITE "Dynamic Decisions in Maintenance".

### References

- Adgar, A., Addison, J.F.D. & Yau, C.-Y. (2007), Applications of RFID technology in maintenance systems, in 'Proc. 2nd World Congress on Engineering Asset Management', Harrogate, UK, 11-14 Jun 2007.
- Al-Najjar B., Alsyof I. (2003). "Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making" International Journal of Production Economics 84, 85-100
- Arnaiz A, Levrat E, Mascolo J, Gorritxategi E (2007) "Scenarios for development and demonstration of dynamic maintenance strategies." ESReDA European Safety, Reliability & Data Analysis) 32nd seminar. Sardinia.. In print.
- Arnaiz A, Maurtua I, Susperregi L, Arana R (2004) "Strategic directions in Maintenance: Knowledge update" International conference IMS-FORUM2004; 300-307
- Baldwin R.C. (2001). "Enabling an E-Maintenance Infrastructure". Maintenance Technology, 12, Available: [http://www.mt-online.com/articles/1201\\_mimosa.cfm](http://www.mt-online.com/articles/1201_mimosa.cfm)
- Bengtsson M. (2003). "Standardization issues in condition based maintenance", Department of Innovation, Design and Product Development, Mälardalen University, Sweden.
- Crespo Marquez A., Gupta J.N.D. (2006). "Contemporary Maintenance Management: Process, Framework and Supporting Pillars". Omega. 34/3, 325-338
- Fensel D (2001) "Ontologies: A silver bullet for Knowledge management and electronic commerce" Springer
- Gilabert E, Arnaiz A. (2006) "Intelligent automation systems for predictive maintenance. A case study" E. Gilabert, A. Arnaiz. Robotics and Computer Integrated Manufacturing (RCIM). Vol 22. (5-6), 543-549.
- Iung B. (2003). "From remote maintenance to MAS-Based E-maintenance of an industrial process". International Journal of Intelligent Manufacturing, 14/1, 59-82
- Jantunen E, Adgar A, Arnaiz A. (2008) "Actors and roles in e-Maintenance" 5th International Conference on Condition Monitoring and Machinery Failure Prevention Technologies. CM2008 and MFPT 2008.
- Komonen K. (2005). "Käynnissä- ja kunnossapidon kehitys 2000-luvulla Suomessa" [Development of availability and maintenance in Finland in the present decade]. Kunnossapito 2, 52-55. (Finnish)
- Lebold M., Reichard K., S.Byington C., Orsagh R (2002) "OSA-CBM Architecture Development with Emphasis on XML Implementations" MARCON 2002.
- Lee J. (2001). "A framework for web-enabled e-Maintenance Systems". Proceedings of the second international symposium on environmentally conscious design and inverse manufacturing, EcoDesign'01
- Takata S. Kimura F., van Houten F.J.A.M. Westkämper E., Shpitalni M., Ceglarek D., Lee J. (2004), "Maintenance: Changing Role in Life Cycle Management" Annals of the CIRP, 53/2, 643 -656